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(54) **DATA STORAGE DEVICE AND SYSTEM HAVING ADAPTIVE BROWNOUT DETECTION**

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G11B 5/02 (2006.01)

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CPC ***G11B 19/047*** (2013.01); *G11B 5/02* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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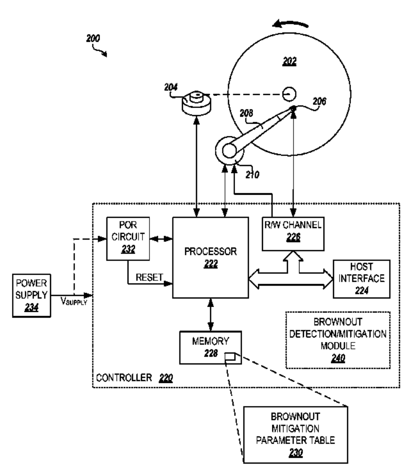
(57) **ABSTRACT**

Technologies are described herein for adaptive brownout detection and mitigation in a storage device having rotational storage media. A target position on the rotational storage media for a current write operation is received. A value for a brownout mitigation parameter is determined based on the target position. A brownout condition is then detected on the storage device, and upon detecting the brownout condition, the current write operation is completed before a power-on reset of the storage device.

20 Claims, 6 Drawing Sheets



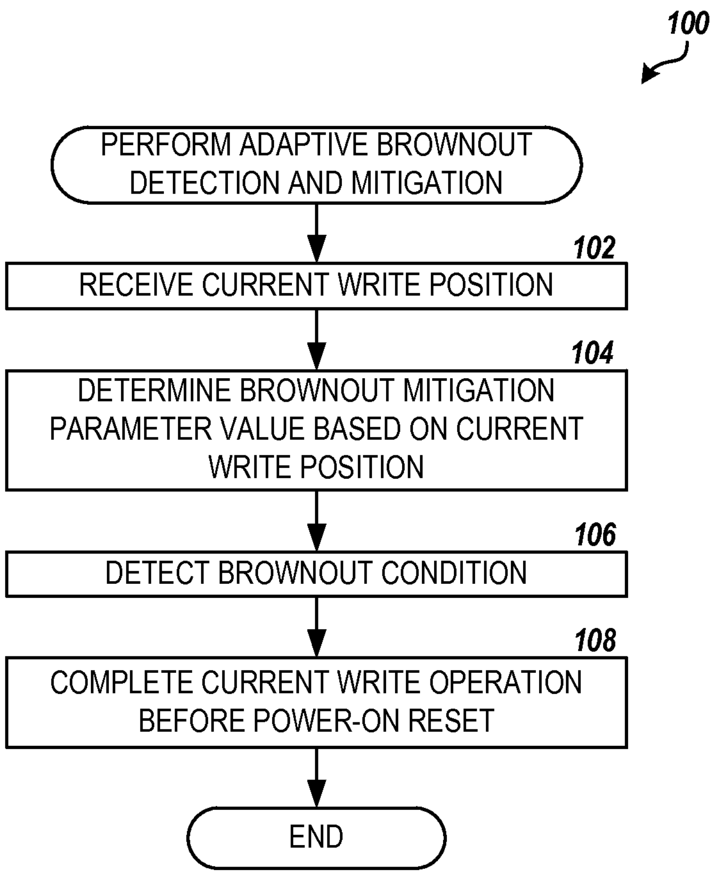

100
PERFORM ADAPTIVE BROWNOUT DETECTION AND MITIGATION
102
RECEIVE CURRENT WRITE POSITION
104
DETERMINE BROWNOUT MITIGATION PARAMETER VALUE BASED ON CURRENT WRITE POSITION
106
DETECT BROWNOUT CONDITION
108
COMPLETE CURRENT WRITE OPERATION BEFORE POWER-ON RESET
END

FIG. 1

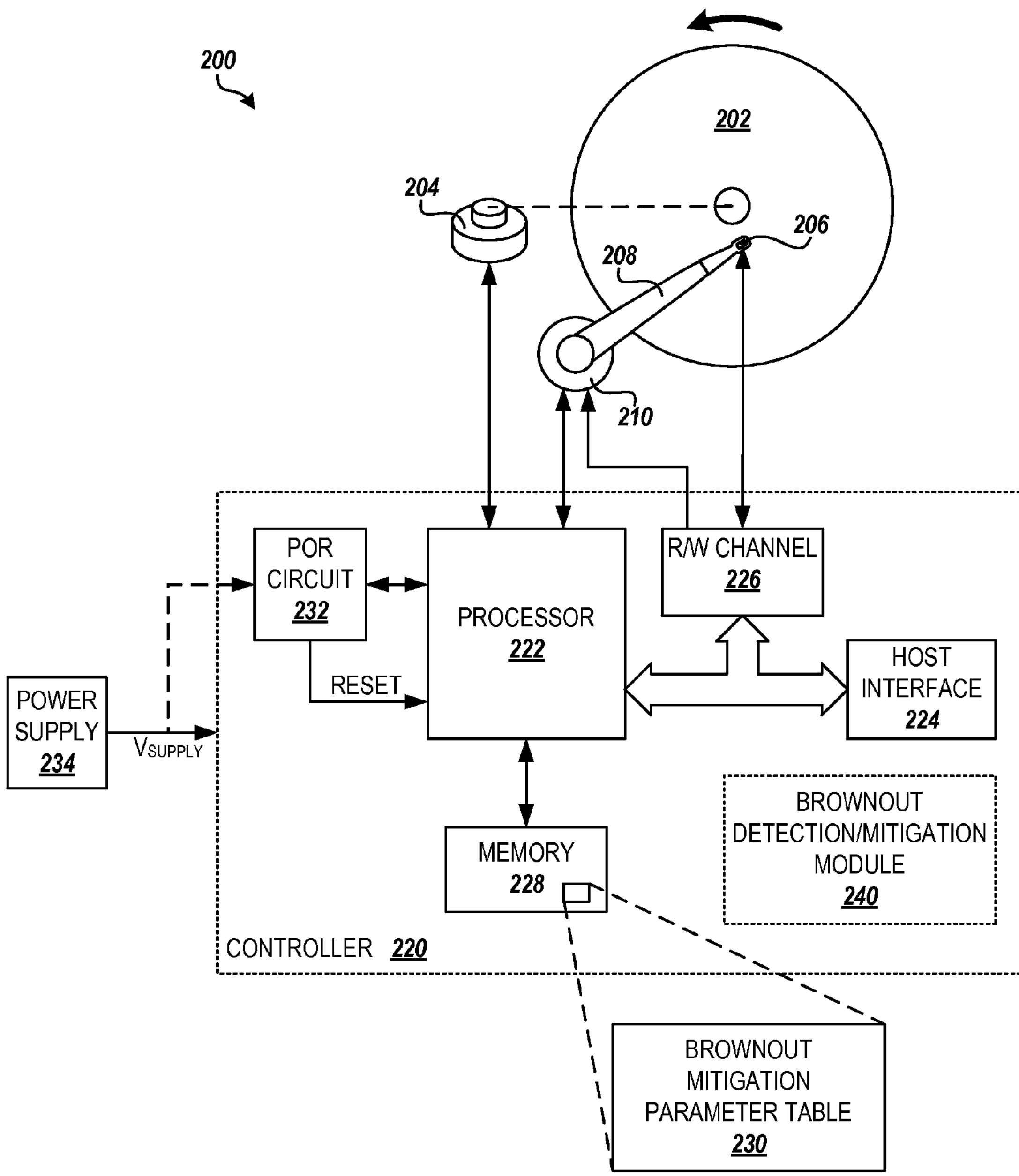

200
202
204
206
208
210
POR
CIRCUIT
232
PROCESSOR
222
R/W CHANNEL
226
HOST
INTERFACE
224
POWER
SUPPLY
234
VSUPPLY
RESET
MEMORY
228
BROWNOUT
DETECTION/MITIGATION
MODULE
240
CONTROLLER 220
BROWNOUT
MITIGATION
PARAMETER TABLE
230

FIG. 2

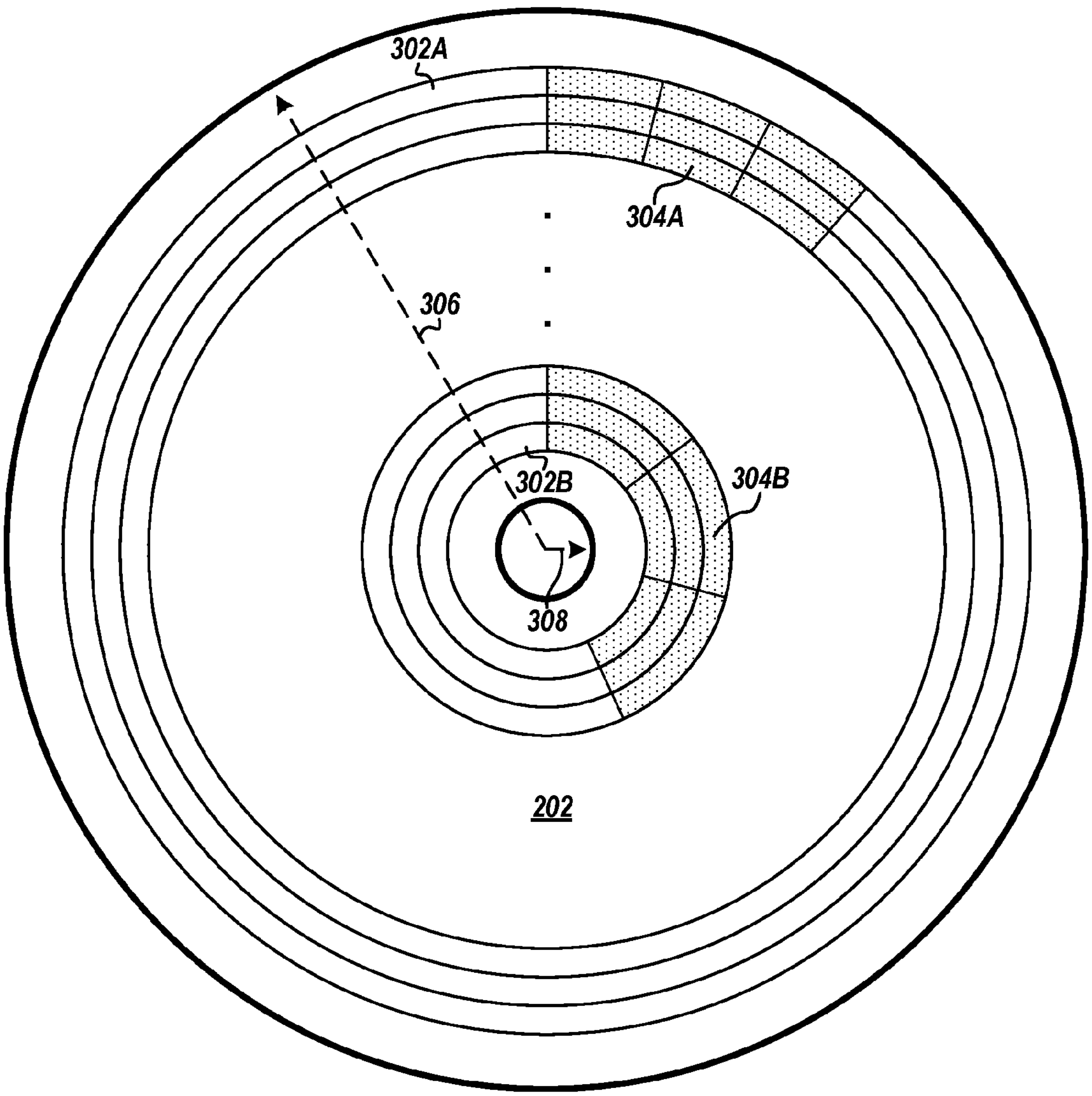


FIG. 3

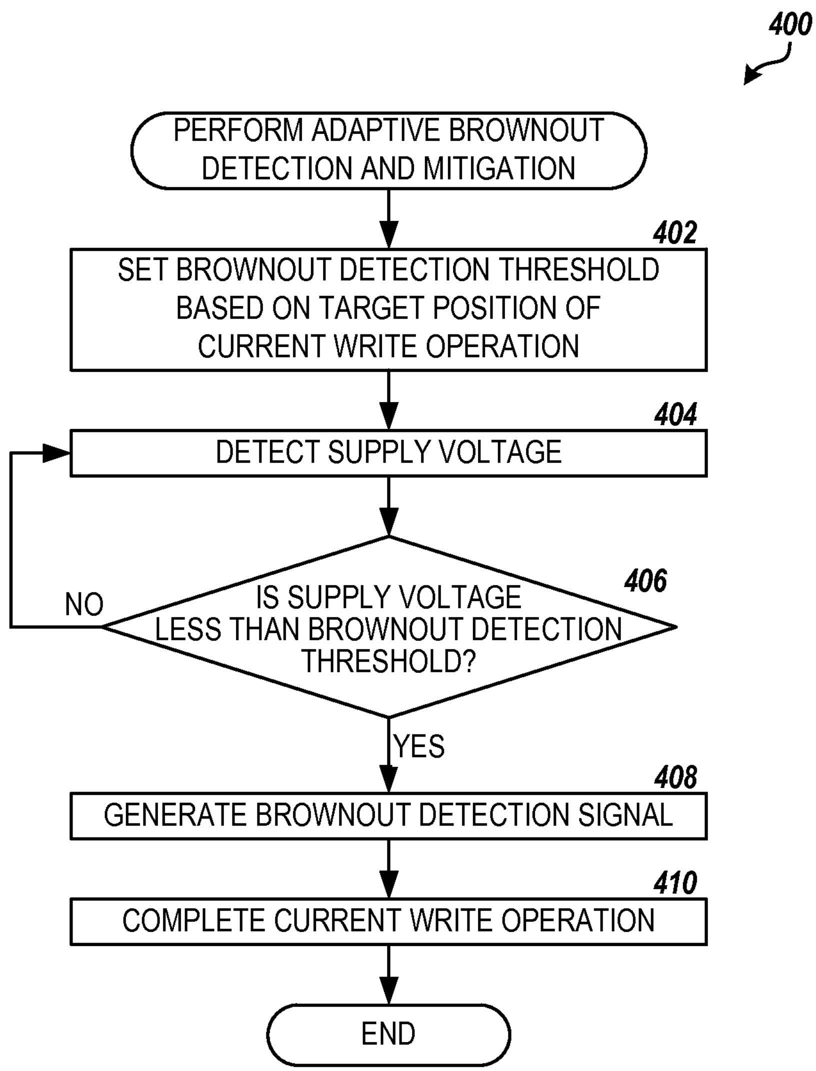

400
PERFORM ADAPTIVE BROWNOUT DETECTION AND MITIGATION
402
SET BROWNOUT DETECTION THRESHOLD BASED ON TARGET POSITION OF CURRENT WRITE OPERATION
404
DETECT SUPPLY VOLTAGE
406
IS SUPPLY VOLTAGE LESS THAN BROWNOUT DETECTION THRESHOLD?
NO
YES
408
GENERATE BROWNOUT DETECTION SIGNAL
410
COMPLETE CURRENT WRITE OPERATION
END

FIG. 4

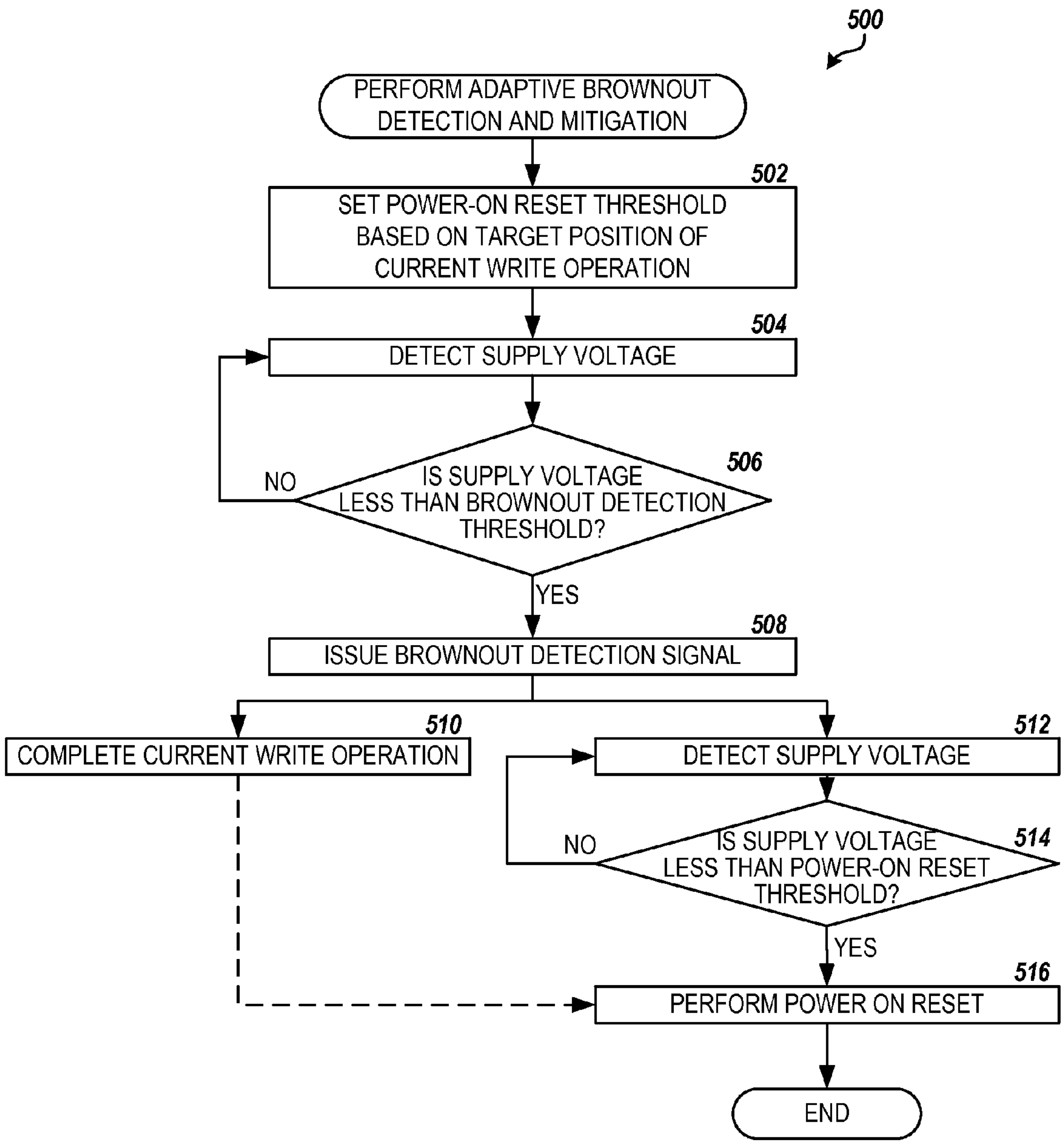

500
PERFORM ADAPTIVE BROWNOUT DETECTION AND MITIGATION
502
SET POWER-ON RESET THRESHOLD BASED ON TARGET POSITION OF CURRENT WRITE OPERATION
504
DETECT SUPPLY VOLTAGE
506
IS SUPPLY VOLTAGE LESS THAN BROWNOUT DETECTION THRESHOLD?
NO
YES
508
ISSUE BROWNOUT DETECTION SIGNAL
510
COMPLETE CURRENT WRITE OPERATION
512
DETECT SUPPLY VOLTAGE
514
IS SUPPLY VOLTAGE LESS THAN POWER-ON RESET THRESHOLD?
NO
YES
516
PERFORM POWER ON RESET
END

FIG. 5

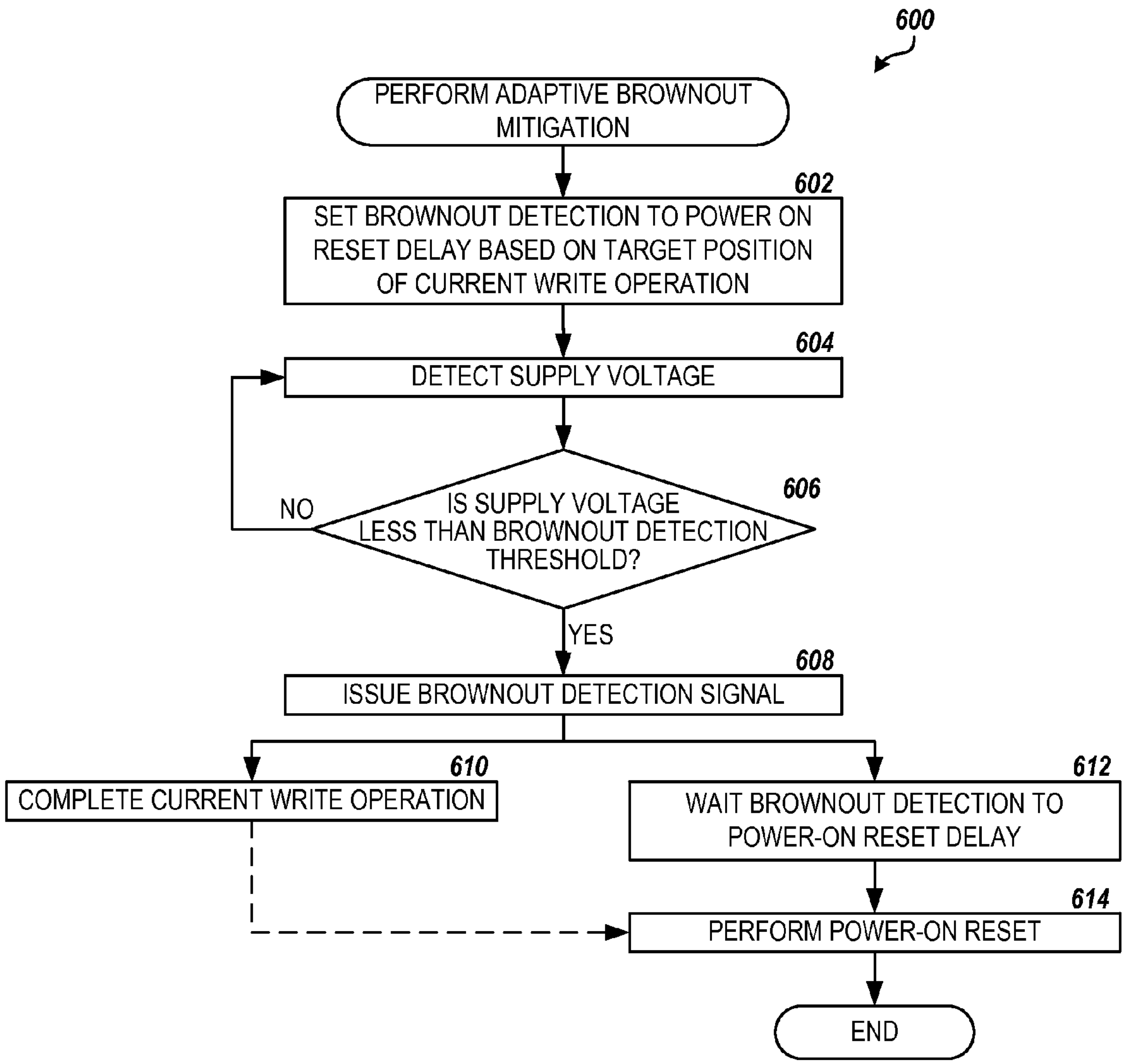

600
PERFORM ADAPTIVE BROWNOUT MITIGATION
602
SET BROWNOUT DETECTION TO POWER ON RESET DELAY BASED ON TARGET POSITION OF CURRENT WRITE OPERATION
604
DETECT SUPPLY VOLTAGE
606
IS SUPPLY VOLTAGE LESS THAN BROWNOUT DETECTION THRESHOLD?
NO
YES
608
ISSUE BROWNOUT DETECTION SIGNAL
610
COMPLETE CURRENT WRITE OPERATION
612
WAIT BROWNOUT DETECTION TO POWER-ON RESET DELAY
614
PERFORM POWER-ON RESET
END

FIG. 6

DATA STORAGE DEVICE AND SYSTEM HAVING ADAPTIVE BROWNOUT DETECTION

BRIEF SUMMARY

The present disclosure relates to technologies for adaptive brownout detection and mitigation in a storage device having rotational storage media, such as a hard-disk drive ("HDD") device. According to some embodiments, a method comprises receiving a target position on a rotational storage media of a storage device for a current write operation. A value for a brownout mitigation parameter is determined based on the target position. A brownout condition is then detected in the storage device, and upon detecting the brownout condition, the current write operation is completed before a power-on reset of the storage device.

According to further embodiments, a computer-readable storage medium comprises processor-executable instructions that, when executed by a processor, cause the processor to receive a target position on a rotational storage media of a storage device for a current write operation. A value for a brownout detection threshold is determined based on the target position. It is then determined whether the supply voltage level is below the value for the brownout detection threshold, and if so, a brownout detection signal is generated and the current write operation is completed.

According to further embodiments, a system comprises a hard disk drive comprising a rotational recording medium and a controller comprising a processor and a memory. The controller may be configured to receive a target position on the rotational storage media for a current write operation and determine a value for a power-on reset threshold based on the target position. The controller may then monitor the supply voltage level for the controller. If it is determined that the supply voltage level is below a configured brownout detection threshold, the controller may generate a brownout detection signal and complete the current write operation. If it is determined that the supply voltage level is below the value for the power-on reset threshold, the controller may perform a power-on reset of the controller.

According to some embodiments, a method of adaptive brownout detection and mitigation in a storage device having rotational storage media comprises receiving a target position on the rotational storage media for a current write operation. A value for a brownout detection to power-on reset delay is determined based on the target position. A brownout condition is then detected in the storage device, and upon detecting the brownout condition, a brownout detection signal is generated and the current write operation is completed. After a period of time indicated by the value for the brownout detection to power-on reset delay expires, a power-one reset of the storage device is performed.

These and other features and aspects of the various embodiments will become apparent upon reading the following Detailed Description and reviewing the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following Detailed Description, references are made to the accompanying drawings that form a part hereof, and that show, by way of illustration, specific embodiments or examples. The drawings herein are not drawn to scale. Like numerals represent like elements throughout the several figures.

FIG. **1** is a flow diagram showing one routine for performing adaptive brownout detection and mitigation in a storage device having rotational media, according to embodiments described herein.

FIG. **2** is a block diagram showing an illustrative environment for adaptive brownout detection and mitigation in a storage device, according to embodiments described herein.

FIG. **3** is a block diagram showing an illustrative layout of data tracks and sectors on disk media, according to embodiments described herein.

FIG. **4** is a flow diagram showing another routine for performing adaptive brownout detection and mitigation in a storage device, according to embodiments described herein.

FIG. **5** is a flow diagram showing another routine for performing adaptive brownout detection and mitigation in a storage device, according to embodiments described herein.

FIG. **6** is a flow diagram showing another routine for performing adaptive brownout detection and mitigation in a storage device, according to embodiments described herein.

DETAILED DESCRIPTION

The following detailed description is directed to technologies for adaptive brownout detection and mitigation in a storage device having rotational storage media. A typical storage device may include a hard-disk drive ("HDD") device. The HDD device may contain a number of magnetic storage disks formatted into a number of concentric data tracks. The data tracks may be further divided into formatted data structures, referred to herein as "sectors," that contain the data stored on the device. The sectors may be of a predefined, fixed length and encoded with user data as well as information used for data recovery by the decoding scheme. If a sector is not completely but only partially recorded onto the disk, data recovery from the partially recorded sector may not be possible since this data recovery information may have been lost. In other words, sectors on the disks not recorded in their entirety may not be successfully read at a later time.

During a power-down of the HDD device, the supply voltage may drop and, upon reaching a certain voltage threshold, a system reset may occur to protect the device from malfunctions that may result in invalid data processing. This may be referred to as a "power-on reset." Typically, the HDD device may cease read and write operations immediately upon the power-on reset. If the power-on reset occurs during a write operation of a sector, the sector may only be partially written to the disk, resulting in data loss.

Some storage devices implement a brownout detection scheme to mitigate such data loss by protecting against write failures during power-down. In these schemes, the supply voltage level may be monitored and a warning signal, referred to as a "brownout detection signal," may be generated when the supply voltage reaches a certain level between normal supply voltage and the power-on reset threshold voltage. For example, in an HDD device with a normal supply voltage of 5 V and a power-on reset threshold of 3.5 V, the brownout detection signal may be generated when the supply voltage reaches 4.3 V. Upon generation of the brownout detection signal, the HDD device may cease accepting new write operations and proceed to complete any write operation(s) in progress. By setting the brownout detection voltage, also referred to herein as the "brownout detection threshold," to a sufficiently-higher voltage than the power-on reset threshold, a sector being written to the disk may be recorded in its entirety before the power-on reset occurs, thus avoiding data loss.

In order to accomplish mitigation of data loss due to partially written sectors, the time between brownout detection and power-on reset should be longer than the time required to complete a write of a sector on the disk. For example, if the supply voltage for an HDD device drops linearly from 5 V to 0 V in 450 μs during power-down, the power-on reset threshold is configured at 3.5 V, and the brownout detection scheme generates the brownout detection signal at 4.3 V, then time between brownout detection and power-on reset would be approximately 72 μs. If worst case time requirement for writing a sector to disk in the HDD device is less than 72 μs, then no write failures should occur during the power-down condition. However, since the HDD device ceases accepting new write operations upon the generation of the brownout detection signal, the overall operational voltage range of the device is limited by the brownout detection threshold, e.g. 4.3 V, instead of the lower power-on reset threshold, e.g. 3.5 V, without the brownout detection scheme.

In data storage devices having rotational storage media, such as the disks of the HDD device in the example above, the time required to complete a write operation of a complete data structure located near the outer radius of the storage media may be shorter than that required to write a data structure near the inner radius of the storage media due to the way in which the media is formatted. For example, for some HDD devices, the write time may be approximately 70 μs for a sector located on a data track near the innermost radius of the disk but only approximately 24 μs for a sector located on a data track near the outermost radius.

According to embodiments, an adaptive brownout detection and mitigation scheme may be implemented in a storage device that takes advantage of the difference in write times between data structures located near the outer radius and those near the inner radius of the rotational media in order to increase the operational voltage range of the device. The parameter values for the adaptive brownout detection and mitigation scheme are not fixed, but may be adjusted to increase or decrease the time between brownout detection and power-on reset based on the radial position of the target data structure on the rotational media for a current write operation. This may result in an overall increase in the operational voltage range of the device when compared to a typical brownout detection scheme with fixed parameter values while maintaining the same level protection against data loss in power-down or other low power conditions.

FIG. **1** provides an overview of adaptive brownout detection and mitigation methods and processes described herein. Specifically, FIG. **1** illustrates one routine **100** for adaptive brownout detection and mitigation in a storage device having rotational storage media, such as an HDD device, according to some embodiments. The routine **100** may be performed during a write operation in the normal operation or "user mode" of the storage device, for example. According to some embodiments, the routine **100** may be performed by a controller of the storage device. The routine **100** includes step **102**, where a position of a target data structure on the storage media for a current write operation is received. The position may comprise a specification of a data track on a disk containing the target sector for the write operation, for example.

From step **102**, the routine **100** proceeds to step **104**, where a value is determined for at least one brownout mitigation parameter based on the position of the target sector. In some embodiments, the brownout mitigation parameter may be a brownout detection threshold, as described above. In other embodiments, the brownout mitigation parameter(s) may comprise a brownout detection threshold, a power-on reset threshold, a brownout detection to power-on reset delay or any combination of these and/or other applicable parameters, as will be described in more detail below. The value for the brownout mitigation parameter(s) may be determined by lookup from a brownout mitigation parameter table based on the position of the target sector, may be calculated based on the position of the target sector and pre-set limits, or may be determined by some other method. For example, the brownout detection threshold value may be determined to be 4.3 V for a target sector on a track near the inner radius of the disk, 3.9 V for a target sector on a track near the outer radius of the disk, and between 4.3 V and 3.9 V based on the radial position of the track of the target sector between the inner and outer radiuses of the disk, respectively.

From step **104**, the routine **100** proceeds to step **106**, where a brownout condition is detected in the storage device. In some embodiments, the detection of the brownout condition may be based on the value determined for the brownout mitigation parameter(s) in step **104**. For example, the brownout condition may detected by the supply voltage of the controller of the storage device dropping below the brownout detection threshold value determined for the position of the target sector of the current write operation on the storage media.

The routine **100** proceeds from step **106** to step **108**, where the current write operation is completed before a power-on reset occurs. According to embodiments, the value determined for the brownout mitigation parameter(s) are configured to provide sufficient time for the current write operation to complete before power-on reset occurs, as will described in more detail below in regard to FIGS. **4-6**. From step **108**, the routine **100** ends.

FIG. **2** and the following description are intended to provide a general description of a suitable environment in which the embodiments described herein may be implemented. In particular, FIG. **2** shows an illustrative storage device **200**, such as an HDD device, along with hardware, software and components for performing adaptive brownout detection and mitigation in the device, according to the embodiments provided herein. The storage device **200** may include rotational storage media comprising at least one platter or disk **202** rotatable by a spindle motor **204** and having a magnetic surface or coating.

The storage device **200** further includes at least one read/write head **206** located adjacent to the surface of each disk **202**. The read/write head **206** may read information from the disk **202** by sensing a magnetic field formed on portions of the surface of the disk, and may write information to the disk by magnetizing a portion of the surface of the disk. The read/write head **206** may be located at the distal end of an arm **208**, the arm being further connected to an actuator **210**, such as a voice coil motor ("VCM"), that repositions the read/write head **206**. It will be appreciated by one of ordinary skill in the art that the read/write head **206** may comprise multiple components, such as a magneto-resistive ("MR") or tunneling MR reader element, a writer element, an air bearing and the like.

The surface of the disk **202** may be divided or "formatted" into a number of individual data tracks, such as data tracks **302**A and **302**B (referred to herein generally as data tracks **302**) shown in FIG. **3**. The data tracks **302** may represent substantially concentric circular areas on the surface of the disk **202**. Each data track **302** may further be divided or formatted into a number of individual data structures or "sectors," such as sectors **304**A and **304**B (referred to herein generally as sectors **304**), for storage of user data. According to embodiments, each sector **304** may contain a fixed number of bits of data storage. For example, each sector **304** may include a fixed length preamble, 4 Kb of user data and a fixed number of bits for error correction or verification data.

In further embodiments, the number of sectors **304** per data track **302** may vary, with a greater number of sectors on the tracks towards the outer radius **306** of the disk **202** and fewer sectors on the tracks towards the inner radius **308** of the disk, as further shown in FIG. **3**. It will be appreciated by one skilled in the art that when the disk **202** is maintained at a constant rotational rate during normal operation of the storage device **200**, the data recording rate for the storage device can vary based on the radial position of the target data track **302**, with faster writes occurring on the outer tracks, such as track **302**A (where there are more sectors **304**), and slower writes occurring on the inner tracks, such as track **302**B (where there are fewer sectors). For example, in some HDD devices, the write time for a sector **304** of data to an outermost data track **302**A may be around 24 μs, while the write time for a sector of data to an innermost data track **302**B may be around 70 μs.

In addition, recording data to an outermost data track **302**A may require more power than that needed for recording data to an innermost data track **302**B due to the higher frequencies involved in recording the sector data in a shorter period of time. For example, some HDD devices write sector data in innermost tracks **302**B at 400 Mbps, while sector data in outermost tracks **302**A may be written at 1.5 Gbps, These devices may consume 1.5 W of power for writing a sector **304** to an outermost data track **302**A while only consuming 0.7 W to write a sector to an innermost data track **302**B.

Returning to FIG. **2**, the storage device **200** may further comprise a controller **220** that controls the operations of the storage device. The controller **220** may include a processor **222** to monitor and control the operations of the storage device **200**. The controller may further include a host interface **224** allowing the storage device **200** to communicate with a host device or other components, such as a server computer, personal computer ("PC"), laptop, tablet, game console, set-top box or any other electronics device that can be communicatively coupled to the storage device **200** to store and retrieve data from the storage device. The controller **220** may process write commands from the host device by formatting the associated data and transfer the formatted data via a read/write channel **226** through the read/write head **206** and to a sector **304** on a target data track **302** on the surface of the disk **202**. The controller **220** may further process read commands from the host device by determining the target data track **302** and sector **304** containing the desired data, moving the read/write head(s) **206** over the determined location, reading the data from the target sector via the read/write channel **226**, correcting any errors and formatting the data for transfer to the host device.

The read/write channel **226** may convert data between the digital signals received by the host interface **224** and/or processed by the processor **222** and the analog signals conducted through the read/write head **206** for reading and writing data to the surface of the disk **202**. The analog signals to and from the read/write head **206** may be further processed through a pre-amplifier circuit. The read/write channel **226** may further provide servo data read from the disk **202** to the actuator **210** to position the read/write head **206**. The read/write head **206** may be positioned to read or write data to the target sector **304** on the surface of the disk **202** by moving the read/write head **206** radially across the data tracks **302** using the actuator **210** while the spindle motor **204** rotates the disk to bring the target sector under the read/write head.

The controller **220** may further include a computer-readable storage medium or "memory" **228** for storing processor-executable instructions, data structures and other information. The memory **228** may comprise a non-volatile memory, such as read-only memory ("ROM") and/or FLASH memory, and a random-access memory ("RAM"), such as dynamic random access memory ("DRAM") or synchronous dynamic random access memory ("SDRAM"). The memory **228** may further comprise a portion of the storage media of the storage device **200**, such as the maintenance cylinder ("M/C") of the disk **202**. For example, the memory **228** may store a firmware that comprises commands and data necessary for performing the operations of the storage device **200**. According to some embodiments, the memory **228** may store processor-executable instructions that, when executed by the processor, perform the routines **100**, **400**, **500** and **600** for performing adaptive brownout detection and mitigation in the storage device **200**, as described herein.

In some embodiments, the memory **228** may store a brownout mitigation parameter table **230**. The brownout mitigation parameter table **230** may store parameter information regarding parameter values utilized by the methods and processes described herein for adaptive brownout detection and mitigation in the storage device **200**, as will be described in more detail below in regard to FIGS. **4-6**. In other embodiments, the brownout mitigation parameter table **230** may be stored in some other computer-readable storage media in or accessible to the controller **220**, including in the M/C of the disk **202**.

In addition to the memory **228**, the environment may include other computer-readable media storing program modules, data structures and other data described herein for performing adaptive brownout detection and mitigation in the storage device **200**. It will be appreciated by those skilled in the art that computer-readable media can be any available media that may be accessed by the controller **220** or other computing system, including computer-readable storage media and communications media. Communications media includes transitory signals. Computer-readable storage media includes volatile and non-volatile, removable and non-removable storage media implemented in any method or technology for the non-transitory storage of information. For example, computer-readable storage media includes, but is not limited to, RAM, ROM, erasable programmable ROM ("EPROM"), electrically-erasable programmable ROM ("EEPROM"), FLASH memory or other solid-state memory technology, compact disc ROM ("CD-ROM"), digital versatile disk ("DVD"), high definition DVD ("HD-DVD"), BLU-RAY or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices and the like.

The storage device may further include a power-on reset ("PoR") circuit **232**. The PoR circuit **232** may monitor the supply voltage (V_{SUPPLY}) provided by a power supply **234** to the controller **220**, provide power-on reset functionality for the processor **222** and other components of the controller **220**, and perform other power supervisory functions. According to embodiments, the PoR circuit **232** may be configured to detect when the supply voltage falls below a voltage threshold, referred to herein as the "power-on reset threshold," and assert a reset signal to the processor **222** and/or other components of the controller **220** in order to reset the processor and other components to a known, stable state. The power-on reset threshold may be fixed at particular value, such 3.5 V, or the power-on reset threshold may be configurable by the processor **222** or other component of the controller **220**.

In further embodiments, the environment may include a brownout detection/mitigation module **240**. The brownout detection/mitigation module **240** may perform the methods and processes described herein for performing adaptive brownout detection and mitigation in the storage device **200**. According to some embodiments, the brownout detection/mitigation module **240** may be implemented in the controller **220** as software, hardware or any combination of the two. For example, the brownout detection/mitigation module **240** may be stored in the memory **228** as part of the firmware of the storage device **200** and may be executed by the processor **222** for performing the methods and processes described herein. The brownout detection/mitigation module **240** may alternatively or additionally be stored in other computer-readable media accessible by the controller **220**.

It will be appreciated that the structure and/or functionality of the storage device **200** may be different that that illustrated in FIG. **2** and described herein. For example, the processor **222**, read/write channel **226**, memory **228**, PoR circuit **232**, power supply **234** and other components and circuitry of the storage device **200** may be integrated within a common integrated circuit package or distributed among multiple integrated circuit packages. Similarly, the illustrated connection pathways are provided for purposes of illustration and not of limitation, and some components and/or interconnections may be omitted for purposes of clarity. It will be further appreciated that the storage device **200** may not include all of the components shown in FIG. **2**, may include other components that are not explicitly shown in FIG. **2** or may utilize an architecture completely different than that shown in FIG. **2**.

FIG. **4** illustrates one routine **400** for performing adaptive brownout detection and mitigation in a storage device **200** having rotational media, according to some embodiments. According to embodiments, the routine **400** may be performed in conjunction with a current write operation of a target sector **304** on a target data track **302** of the disk **202** during user mode operation of the storage device **200**. In some embodiments, the routine **400** may be performed by the brownout detection/mitigation module **240** described above in regard to FIG. **2**. In further embodiments, the routine **400** may be performed by the controller **220** of the storage device **200**, by external processors or computing systems accessing data from the device or some other combination of modules, processors and devices.

The routine **400** begins at step **402**, where the brownout detection/mitigation module **240** sets a value for the brownout detection threshold based on the target position of the current write operation. The value for the brownout detection threshold may be configured to provide sufficient time between detection of the brownout condition and power-on reset for the current write operation to complete. In some embodiments the brownout detection threshold value may be determined based on a combination of a number of factors, including the normal supply voltage of the storage device **200**, the configured power-on reset threshold, the rate of drop in supply voltage in a power-down of device, the typical write time of a sector **304** on the target data track **302** and the like. These factors may be determined for the storage device **200** during design or manufacturer of the device and/or during a "burn-in" or certification ("CERT") processing of the storage device, for example.

For example, an HDD device may have a normal supply voltage of 5 V, a power-on reset threshold configured at 3.5 V, and a typical time for supply voltage drop to 0 V at power-down of 450 μs linearly. Further, the write time for the HDD device may be approximately 70 μs for a sector **304** located on a data track **302** near the inner radius **308** of the disk **202** and approximately 24 μs for a sector located on a data track near the outer radius **306** of the disk. For this HDD device, the brownout detection threshold may be set at a value of 4.3 V for a target data track **302** near the inner radius **308** of the disk **202**, at a value of 3.9 V for a target track near the outer radius **306** of the disk, and at a value between 4.3 V and 3.9 V for target tracks between the inner and outer radiuses of the disk, respectively.

In some embodiments, the value for the brownout detection threshold may be determined by lookup from the brownout mitigation parameter table **230** described in regard to FIG. **2** based on the radial position of the target track **302**. For example, the data tracks **302** of the disk **202** may be grouped into a number of zones, with the data tracks in each zone containing the same number of sectors **304**. The brownout mitigation parameter table **230** may contain an entry for each zone with a corresponding value for the brownout detection threshold for target data tracks **302** within that zone in a form shown below in TABLE 1:

TABLE 1

Storage of Brownout Detection Threshold Values

Zone ID	Brownout Detection Threshold Voltage
0	4.30 V
1	4.12 V
. . .	. . .
N	3.90 V

The entries in the brownout mitigation parameter table **230** may be determined based on the normal supply voltage of the storage device **200**, the configured power-on reset threshold, the typical or worst case rate of drop in supply voltage in a power-down of the storage device, and the typical write time of a sector **304** on a data track **302** in each zone, for example. In further embodiments, the entries in the brownout mitigation parameter table **230** may correspond to various ranges of data tracks **302**, to individual tracks or to some other identifier of the target data track. The entries in the brownout mitigation parameter table **230** may be determined during design and/or or CERT processing of the storage device **200**, and written into the table stored in the non-volatile memory **228**, the M/C of the disk **202** or other storage area of the device.

It will be appreciated by one skilled in the art that the tabular data shown in the tables herein is provided for illustrative purposes only, and that the brownout mitigation parameter table **230** may represent a data file, a database table, an object stored in a computer memory, a programmatic structure or any other data container commonly known in the art. Each data element included in the data structure may represent one or more fields in a data file, one or more columns of a database table, one or more attributes of an object, one or more member variables of a programmatic structure or any other unit of data of a data structure commonly known in the art. The implementation is a matter of choice, and may depend on the technology, performance and other requirements of the processor **222**, controller **220** or other elements of the storage device **200** in which the data structures are implemented. It will be further appreciated that the entries in the brownout mitigation parameter table **230** may contain additional data elements beyond those shown in the tables and described herein.

In further embodiments, the value for the brownout detection threshold may be calculated in real-time based on the radial position of the target data track **302** between the inner radius **308** and outer radius **306** of the disk **202** and maximum and minimum brownout detection threshold values determined for the storage device **200**. It will be further appreciated that the value for the brownout detection threshold may be determined by any number of methods known in the art and based on any number of factors beyond those described herein, and it is intended that all such methods and factors be included in this application.

From step **402**, the routine **400** proceeds to step **404**, where the brownout detection/mitigation module **240** detects the current supply voltage level of the storage device **200**. In some embodiments, the current supply voltage level may be determined by querying the PoR circuit **232**. In other embodiments, the current supply voltage level may be detected directly from the power supply **234** or through another method. Next, the routine **400** proceeds to step **406**, where the brownout detection/mitigation module **240** determines if the supply voltage level is less than the brownout detection threshold value set for the current write operation in step **402**. If the supply voltage level is not less than the brownout detection threshold value set for the current write operation, the routine **400** returns to step **404**, where the brownout detection/mitigation module **240** continues to monitor the current supply voltage level of the storage device **200**.

If the supply voltage level is less than the brownout detection threshold value set for the current write operation, the routine **400** proceeds from step **406** to step **408**, where the brownout detection/mitigation module **240** generates a brownout detection signal in the controller **220** of the storage device **200**. As described above, upon generation of the brownout detection signal, the storage device **200** may cease accepting new write operations, according to some embodiments.

From step **408**, the routine **400** proceeds to step **410**, where the current write operation is completed. As described above, the value for the brownout detection threshold determined in step **402** is configured to provide sufficient time after detection of the brownout condition to complete the write of the target sector **304** in its entirety to the disk **202** before power-on reset. In this way, data loss due to partial or incompletely written sectors **304** can be avoided while allowing for the widest overall operational voltage range of the storage device **200**. From step **410**, the routine **400** ends.

FIG. **5** illustrates another routine **500** for performing adaptive brownout detection and mitigation in a storage device **200** having rotational media, according to some embodiments. Similarly to routine **400** described above, the routine **500** may be performed in conjunction with a current write operation of a target sector **304** on a target data track **302** of the disk **202** during user mode operation of the storage device **200**. In some embodiments, the routine **500** may be performed by the brownout detection/mitigation module **240** in conjunction with the PoR circuit **232** described above in regard to FIG. **2**. In further embodiments, the routine **500** may be performed by the controller **220** of the storage device **200**, by external processors or computing systems accessing data from the device or some other combination of modules, processors and devices.

The routine **500** begins at step **502**, where the brownout detection/mitigation module **240** sets a value for the power-on reset threshold based on the target position of the current write operation. The value for the power-on reset threshold may be set by the brownout detection/mitigation module **240** by sending a signal to the PoR circuit **232**, for example. The value for the power-on reset threshold may be configured to provide sufficient time between detection of a brownout condition and power-on reset for the current write operation to complete. By setting the power-on reset threshold to lower levels for target data tracks **302** near the inner radius **308** of the disk **202**, more time can be provided for write operations targeting inner tracks to complete before power-on reset occurs. This scheme is further beneficial in circumstances where the power consumption for writing data to outermost data tracks **302**A of the disk **202** is higher than that required for innermost data tracks **302**B, as described above in regard to FIG. **3**. By setting higher power-on reset voltage levels when writing to outermost data tracks **302**A, power stability can be guaranteed for outer radius recording requiring higher power consumption without losing data loss protection for slower write times for innermost data tracks **302**B.

In some embodiments the power-on reset threshold value may be determined based on a combination of a number of factors, including the normal supply voltage of the storage device **200**, the configured brownout detection threshold, rate of drop in supply voltage in a power-down of the device, the typical write time of a sector **304** on the target data track **302** and the like. As described above, these factors may be determined for the storage device **200** during design and/or CERT processing of the device.

For example, an HDD device may have a normal supply voltage of 5 V, a brownout detection threshold configured at 4.3 V, and a typical time for supply voltage drop to 0 V at power-down of 280 μs linearly. Further, the write time for the HDD device may be approximately 70 μs for a sector **304** located on a data track **302** near the inner radius **308** of the disk **202** and approximately 24 μs for a sector located on a data track near the outer radius **306** of the disk. For this HDD device, the power-on reset threshold may be set at a value of 3.0 V for a target data track **302** near the inner radius **308** of the disk **202**, at a value of 3.5 V for a target track near the outer radius **306** of the disk, and at a value between 3.0 V and 3.5 V for target tracks between the inner and outer radiuses of the disk, respectively.

In some embodiments, the value for the power-on reset threshold may be determined by lookup from the brownout mitigation parameter table **230** based on the radial position of the target track **302**. For example, similar to the example described above in regard to TABLE 1, the brownout mitigation parameter table **230** may contain an entry for each zone with a corresponding value for the power-on reset threshold for target data tracks **302** within that zone in a form shown below in TABLE 2:

TABLE 2

Storage of Power-On Reset Threshold Values

Zone ID	Power-on Reset Threshold Voltage
0	3.00 V
1	3.12 V
. . .	. . .
N	3.50 V

The entries in the brownout mitigation parameter table **230** may be determined based on the normal supply voltage of the storage device **200**, the configured brownout detection threshold, the rate of drop in supply voltage in a power-down of the device, and the typical write time of a sector **304** on a data track **302** in each zone, for example. In further embodiments, the value for the power-on threshold may be calculated in real-time based on the radial position of the target data track **302** between the inner radius **308** and outer radius **306** of the disk and minimum and maximum power-on reset threshold values determined for the storage device **200**. It will be further appreciated that the value for the power-on reset threshold may be determined by any number of methods known in the art and based on any number of factors beyond those described herein, and it is intended that all such methods and factors be included in this application.

From step **502**, the routine **500** proceeds to step **504**, where the brownout detection/mitigation module **240** detects the current supply voltage level of the storage device **200**. In some embodiments, the current supply voltage level may be determined by querying the PoR circuit **232**. In other embodiments, the current supply voltage level may be detected directly from the power supply **234** or through another method. Next, the routine **500** proceeds to step **506**, where the brownout detection/mitigation module **240** determines if the supply voltage level is less than the configured brownout detection threshold value. If the supply voltage level is not less than the configured brownout detection threshold, the routine **500** returns to step **504**, where the brownout detection/mitigation module **240** continues to monitor the current supply voltage level of the storage device **200**.

If the supply voltage level is less than the configured brownout detection threshold, the routine **500** proceeds from step **506** to step **508**, where the brownout detection/mitigation module **240** generates a brownout detection signal in the controller **220** of the storage device **200**. As described above, upon generation of the brownout detection signal, the storage device **200** may cease accepting new write operations, according to some embodiments.

From step **508**, the routine **500** proceeds to step **510**, where the current write operation is completed. While the current write operation completes, the PoR circuit **232** may detect the current supply voltage level of the storage device, at step **512**. The routine proceeds from step **512** to step **514**, where the PoR circuit determines if the supply voltage level is less than the power-on reset threshold value set for the current write operation in step **502**. If the supply voltage level is not less than the power-on reset threshold value set for the current write operation, the routine **500** returns to step **512**, where the PoR circuit **232** continues to monitor the current supply voltage level of the storage device **200**.

If the supply voltage level is less than the power-on reset threshold value set for the current write operation, the routine **500** proceeds from step **514** to step **516**, where the PoR circuit **232** performs a power-on reset of the controller **220** of the storage device **200**. As described above, the value for the power-on reset threshold determined in step **502** is configured to provide sufficient time after detection of the brownout condition to complete the write of the target sector **304** in its entirety to the disk **202** before power-on reset. In this way, data loss due to partial or incompletely written sectors **304** can be avoided while providing for sufficient power to complete the current write operation. From step **516**, the routine **500** ends.

FIG. **6** illustrates another routine **600** for performing adaptive brownout detection and mitigation in a storage device **200** having rotational media, according to some embodiments. Similarly to routines **400** and **500** described above, the routine **600** may be performed in conjunction with a current write operation of a target sector **304** on a target data track **302** of the disk **202** during user mode operation of the storage device **200**. In some embodiments, the routine **600** may be performed by the brownout detection/mitigation module **240** described above in regard to FIG. **2**. In further embodiments, the routine **600** may be performed by the controller **220** of the storage device **200**, by external processors or computing systems accessing data from the device or some other combination of modules, processors and devices.

The routine **600** begins at step **602**, where the brownout detection/mitigation module **240** sets a value for a brownout detection to power-on reset delay based on the target position of the current write operation. According to embodiments, the brownout detection to power-on reset delay represents a delay after a brownout condition is detected until a power-on reset is performed. The value for the brownout detection to power-on reset delay may be configured to provide sufficient time for the current write operation to complete. However, if brownout detection to power-on reset delay is too long and/or the supply voltage drop during power-down is too rapid, the power-on reset may occur at a lower supply voltage level than that required to guarantee power stability in the storage device **200**. By setting the brownout detection to power-on reset delay to shorter intervals for target data tracks **302** near the outer radius **306** of the disk **202**, the power-on reset will occur at a higher supply voltage level ensuring power stability for outer radius recording requiring higher power consumption without losing data loss protection for slower write times for innermost data tracks.

In some embodiments the brownout detection to power-on reset delay value may be set to a value greater than the typical write time of a sector **304** on the target data track **302**. As described above, this time may be determined for the storage device **200** during design and/or CERT processing of the storage device. For example, an HDD device may have a write time of approximately 70 μs for a sector **304** located on a data track **302** near the inner radius **308** of the disk **202** and of approximately 24 μs for a sector located on a data track near the outer radius **306** of the disk. For this HDD device, the brownout detection to power-on reset delay may be set at 72 μs for a target data track **302** near the inner radius **308** of the disk **202**, at a value of 25 μs for a target track near the outer radius **306** of the disk, and at a value between 72 μs and 25 μs for target tracks between the inner and outer radiuses of the disk, respectively.

In some embodiments, the value for the brownout detection to power-on reset delay may be determined by lookup from the brownout mitigation parameter table **230** based on the radial position of the target track **302**. For example, similar to the example described above in regard to TABLE 1, the brownout mitigation parameter table **230** may contain an entry for each zone with a corresponding value for the brownout detection to power-on reset delay for target data tracks **302** within that zone in a form shown below in TABLE 3:

TABLE 3

Storage of Brownout Detection to Power-On Reset Delay Values

Zone ID	Brownout Detection to Power-On Reset Delay
0	72 μs
1	68 μs
. . .	. . .
N	25 μs

The entries in the brownout mitigation parameter table **230** may be determined based on the typical write time of a sector **304** on a data track **302** in each zone, for example. In further embodiments, the value for the brownout detection to power-on reset delay may be calculated in real-time based on the radial position of the target data track **302** between the inner radius **308** and outer radius **306** of the disk and maximum and minimum brownout detection to power-on reset delay values determined for the storage device **200**. It will be further appreciated that the value for the brownout detection to power-on reset delay may be determined by any number of methods known in the art and based on any number of factors beyond those described herein, and it is intended that all such methods and factors be included in this application.

From step **602**, the routine **600** proceeds to step **604**, where the brownout detection/mitigation module **240** detects the current supply voltage level of the storage device **200**. In some embodiments, the current supply voltage level may be determined by querying the PoR circuit **232**. In other embodiments, the current supply voltage level may be detected directly from the power supply **234** or through another method. Next, the routine **600** proceeds to step **606**, where the brownout detection/mitigation module **240** determines if the supply voltage level is less than the configured brownout detection threshold value, such as 4.3 V. If the supply voltage level is not less than the configured brownout detection threshold, the routine **600** returns to step **604**, where the brownout detection/mitigation module **240** continues to monitor the current supply voltage level of the storage device **200**.

If the supply voltage level is less than the configured brownout detection threshold, the routine **600** proceeds from step **606** to step **608**, where the brownout detection/mitigation module **240** generates a brownout detection signal in the controller **220** of the storage device **200**. As described above, upon generation of the brownout detection signal, the storage device **200** may cease accepting new write operations, according to some embodiments.

From step **608**, the routine **600** proceeds to step **610**, where the current write operation is completed. While the current write operation completes, the routine **600** waits the brownout detection to power-on reset delay period set for the current write operation in step **602**, as shown at step **612**. The delay may be implemented by the brownout detection/mitigation module **240**, the PoR circuit **232**, the processor **222** or some other module or component of the controller **220**. Upon expiration of the brownout detection to power-on reset delay, the routine proceeds from step **612** to step **614**, where the PoR circuit **232** performs a power-on reset of the controller **220** of the storage device **200**. As described above, the value for the brownout detection to power-on reset delay determined in step **602** is configured to provide sufficient time after detection of the brownout condition to complete the write of the target sector **304** in its entirety to the disk **202** before power-on reset. In this way, data loss due to partial or incompletely written sectors **304** can be avoided while providing for sufficient power to complete the write. From step **614**, the routine **600** ends.

Based on the foregoing, it will be appreciated that technologies for adaptive brownout detection and mitigation in a storage device having rotational storage media are presented herein. While embodiments are described herein in regard to an HDD device, it will be appreciated that the embodiments described in this disclosure may be utilized in any storage device containing data stored in sector units in substantially concentric data tracks on rotational storage media, including but not limited to, a magnetic disk drive, a hybrid magnetic and solid state drive, an optical disk storage device and the like. The above-described embodiments are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the present disclosure.

The logical steps, functions or operations described herein as part of a routine, method or process may be implemented (1) as a sequence of processor-implemented acts, software modules or portions of code running on a controller or computing system and/or (2) as interconnected machine logic circuits or circuit modules within the controller or computing system. The implementation is a matter of choice dependent on the performance and other requirements of the system. Alternate implementations are included in which steps, operations or functions may not be included or executed at all, may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present disclosure.

It will be further appreciated that conditional language, such as, among others, “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more particular embodiments or that one or more particular embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

Many variations and modifications may be made to the above-described embodiments without departing substantially from the spirit and principles of the present disclosure. Further, the scope of the present disclosure is intended to cover any and all combinations and sub-combinations of all elements, features and aspects discussed above. All such modifications and variations are intended to be included herein within the scope of the present disclosure, and all possible claims to individual aspects or combinations of elements or steps are intended to be supported by the present disclosure.

What is claimed is:

1. A method comprising steps of:

receiving a target position on a rotational storage media of a storage device for a current write operation;

determining a value for a brownout mitigation parameter based on the target position;

detecting a brownout condition in the storage device; and

upon detecting the brownout condition in the storage device, completing the current write operation before a power-on reset of the storage device.

2. The method of claim **1**, wherein the value determined for the brownout mitigation parameter is configured to provide sufficient time between detection of the brownout condition and the power-on reset of the storage device for the current write operation to complete.

3. The method of claim **1**, wherein the value for the for the brownout mitigation parameter is based on one or more of a normal supply voltage of the storage device, a configured brownout detection threshold, a configured power-on reset threshold, a rate of drop in supply voltage in a power-down of the storage device, and a typical write time of a data structure at the target position on the rotational storage media.

4. The method of claim **1**, wherein the brownout mitigation parameter comprises a brownout detection threshold, and wherein detecting the brownout condition in the storage device further comprises:

detecting a supply voltage level for the storage device; and

determining whether the supply voltage level is below the value for the brownout detection threshold.

5. The method of claim **4**, wherein the value determined for the brownout detection threshold is less for target positions closer to an outer radius of the rotational storage media than for target positions closer to an inner radius of the rotational storage media.

6. The method of claim 1, wherein the brownout mitigation parameter comprises a brownout detection to power-on reset delay, the method further comprising the steps of:
- waiting a period of time indicated by the value of the brownout detection to power-on reset delay; and
- upon expiration of the period of time, performing the power-on reset of the storage device.

7. The method of claim 6, wherein the value determined for the brownout detection to power-on reset delay is based on a typical write time of a data structure at the target position on the rotational storage media.

8. The method of claim 6, wherein the value determined for the brownout detection to power-on reset delay is greater for target positions closer to an outer radius of the rotational storage media than for target positions closer to an inner radius of the rotational storage media.

9. The method of claim 1, wherein the brownout mitigation parameter comprises a power-on reset threshold, the method further comprising the steps of:
- detecting a supply voltage level for the storage device;
- determining whether the supply voltage level is below the value for the power-on reset threshold; and
- upon determining that the supply voltage level is below the value for the power-on reset threshold, performing the power-on reset of the storage device.

10. The method of claim 9, wherein the value determined for the power-on reset threshold is less for target positions closer to an inner radius of the rotational storage media than for target positions closer to an outer radius of the rotational storage media.

11. A non-transitory computer-readable storage medium having processor-executable instructions stored thereon that, when executed by a processor, cause the processor to:
- receive a target position on a rotational storage media of a storage device for a current write operation;
- determine a value for a brownout detection threshold based on the target position;
- detect a supply voltage level for the storage device; and
- determine whether the supply voltage level is below the value for the brownout detection threshold; and
- upon determining that the supply voltage level is below the value for the brownout detection threshold, generate a brownout detection signal and complete the current write operation.

12. The computer-readable storage medium of claim 11, wherein the value for the brownout detection threshold is based on one or more of a normal supply voltage of the storage device, a configured power-on reset threshold, a rate of drop in supply voltage in a power-down of the storage device, and a typical write time of a data structure at the target position on the rotational storage media.

13. The computer-readable storage medium of claim 11, wherein the value determined for the brownout detection threshold is less for target positions closer to an outer radius of the rotational storage media than for target positions closer to an inner radius of the rotational storage media.

14. The computer-readable storage medium of claim 11, wherein the value for the brownout detection threshold is retrieved from an entry in a brownout mitigation parameter table stored in a memory of the storage device, the entry corresponding to the target position on the rotational storage media.

15. The computer-readable storage medium of claim 11, wherein generating the brownout detection signal causes the storage device to stop accepting new write operations.

16. A system comprising:
- a hard disk drive comprising rotational storage media; and
- a controller comprising a processor and a memory, the controller configured to
  - receive a target position on the rotational storage media for a current write operation,
  - determine a value for a power-on reset threshold based on the target position,
  - detect a supply voltage level for the controller,
  - determine whether the supply voltage level is below a configured brownout detection threshold,
  - upon determining that the supply voltage level is below the configured brownout detection threshold, generate a brownout detection signal and complete the current write operation,
  - determining whether the supply voltage level is below the value for the power-on reset threshold, and
  - upon determining that the supply voltage level is below the value for the power-on reset threshold, performing a power-on reset of the controller.

17. The system of claim 16, wherein the value for the power-on reset threshold is based on one or more of a normal supply voltage of the controller, the configured brownout detection threshold, a rate of drop in supply voltage in a power-down of the controller, and a typical write time of a data structure at the target position on the rotational storage media.

18. The system of claim 16, wherein the value determined for the power-on reset threshold is less for target positions closer to an inner radius of the rotational storage media than for target positions closer to an outer radius of the rotational storage media.

19. The system of claim 16, wherein the value for the power-on reset threshold is retrieved from an entry in a brownout mitigation parameter table stored in the memory, the entry corresponding to the target position on the rotational storage media.

20. The system of claim 16, wherein determining whether the supply voltage level is below the value for the power-on reset threshold and performing the power-on reset of the controller are performed by a power-on reset circuit configured with the power-on reset threshold by the controller.

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